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Cryogenic Distribution System for Polish Free Electron Laser Facility

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POLFEL - located in National Center for Nuclear Research, Warsaw, Poland

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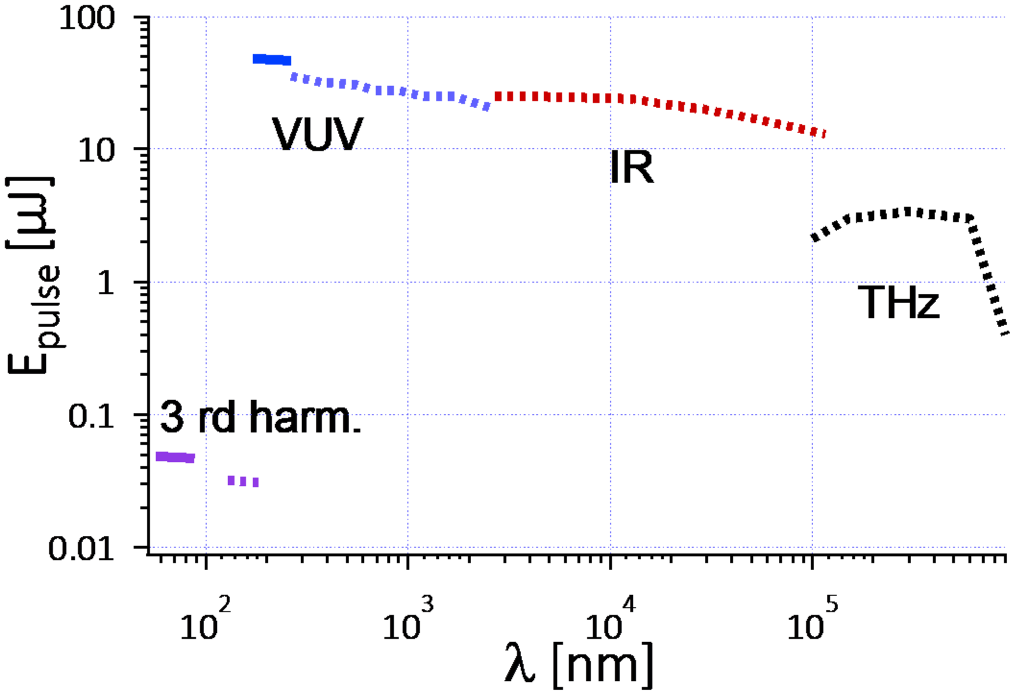
Preliminary beams parameters



PolFEL will be a free electron laser

- built in superconducting TESLA technology
- all superconducting and operating in continues RF mode
- emitting coherent electromagnetic radiation in the range from THz to VUV
- and delivering them to the experimental stations

▪ ▪ ▪ K=1 – 3.5, B < 0.75 T, σ_z=50 µm, $\varepsilon < 2\cdot\pi\cdot 10^{-6}$ dE/E= 0.5 10^{-3} gaussian bunch

▬ $\varepsilon= 0.4\cdot\pi\cdot 10^{-6}$

NARODOWE CENTRUM BADAŃ JĄDROWYCH ŚWIERK

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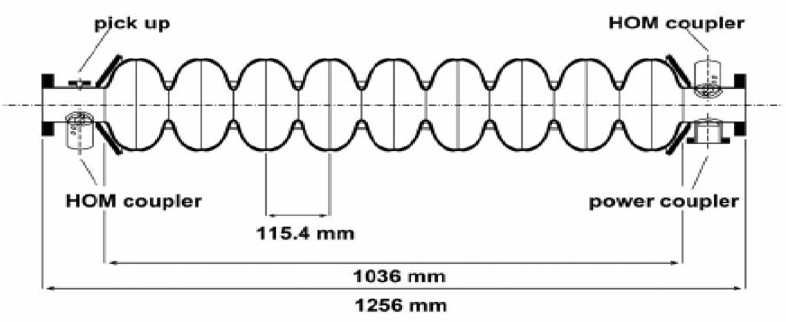
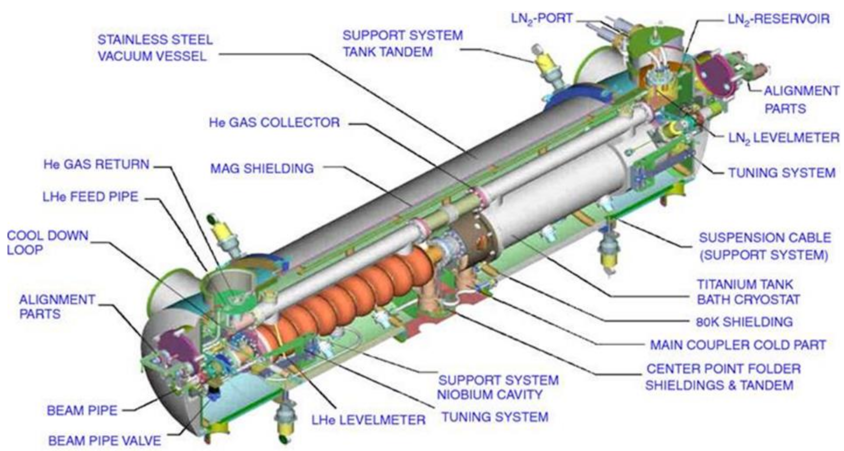
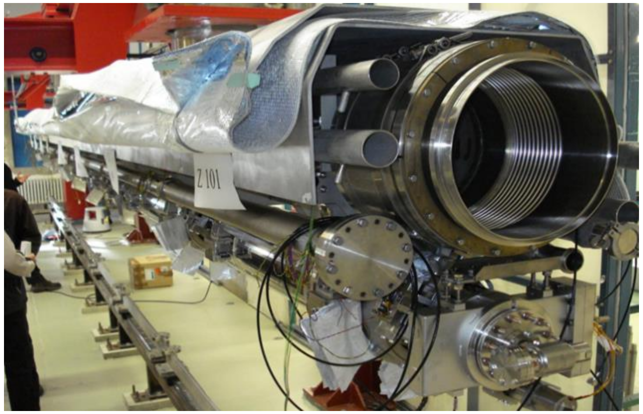
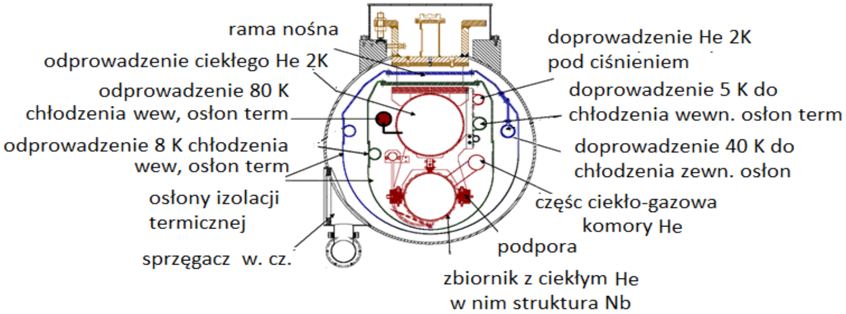
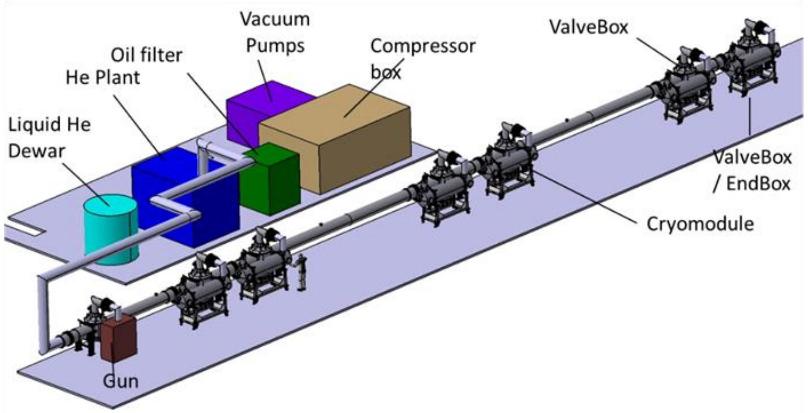
Main Subsystems - Cryomodule with SRF cawities



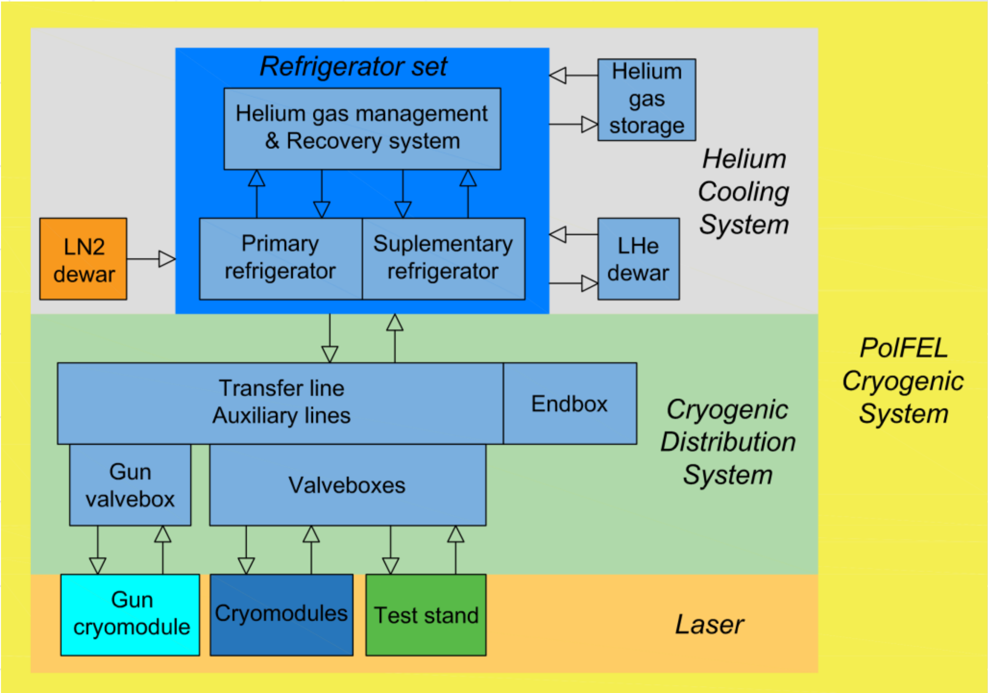








PolFEL cryogenic system



Helium Cooling System provides helium in two thermodynamic states:

- supercritival (**5 K, 4 bara**)
- cold gas state (**40 K, 13 bara**)

Crygenic Distribution System provides helium to the cryomodules at three temperatures:

- **40 K – 80 K** – for cooling the cryomodule and the Cryogenic Distribution System thermal shields (cold gas state)
- **5 K** – for cooling the power couplers of the the accelerating cryomodules (supercritical state)
- **2 K** – for cryostating the resonance cavities of the cryomodules (superfluid state)

Superfluid helium is obtained in the valve boxes

Heat loads @ 2 K

Static heat loads at 2 K

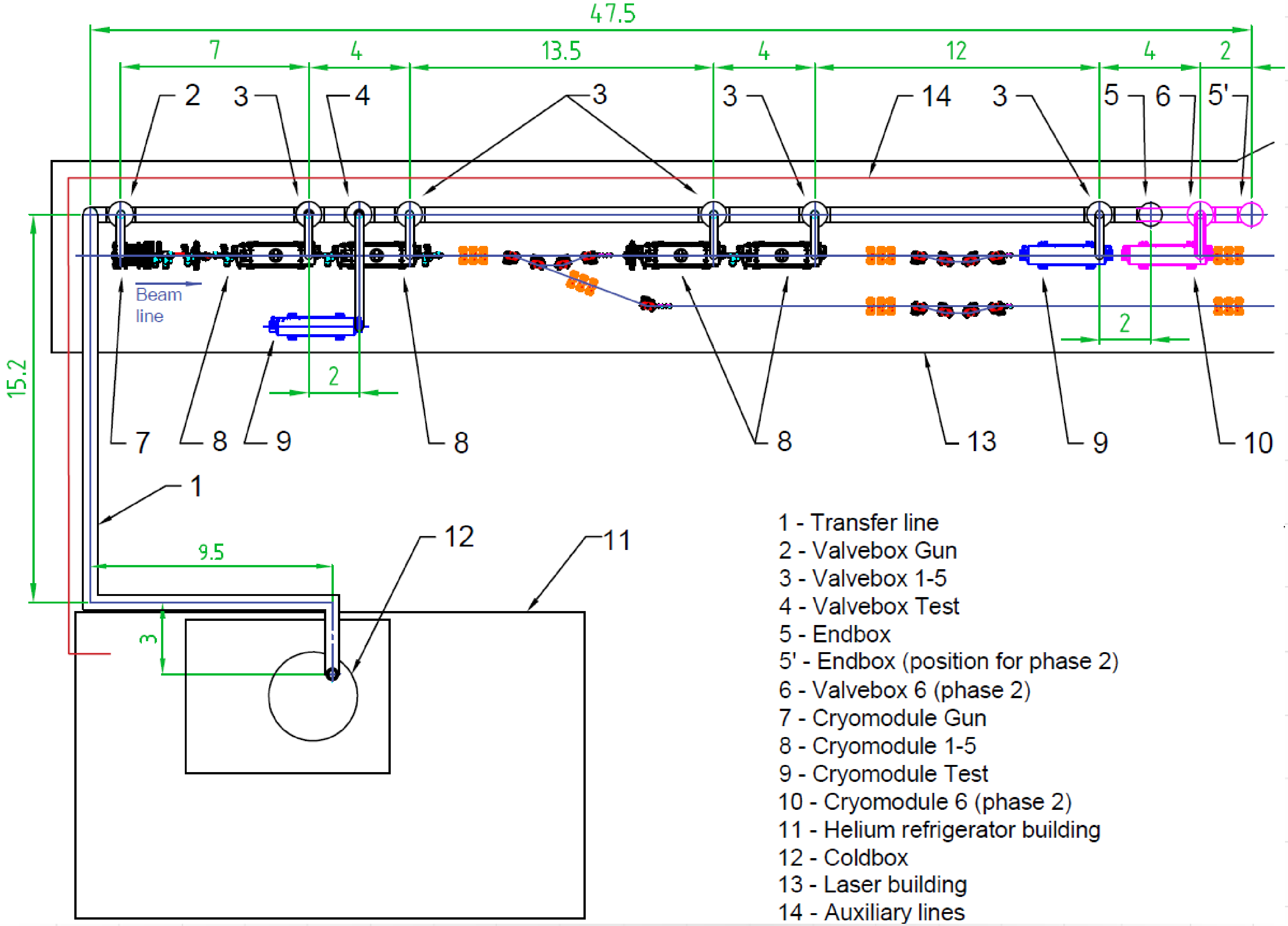
Static heat loads @ 2 K have been estimated for 72 W and they are comprised of:
40 W to HZDR-like cryomodules (conservatively 10 W per cryomodule),
15 W to superconducting SRF electron gun (including dynamic losses)
17 W to external transfer line (0,2 W/m, 85 m of transfer lines).

Dynamic heat loads at 2 K.

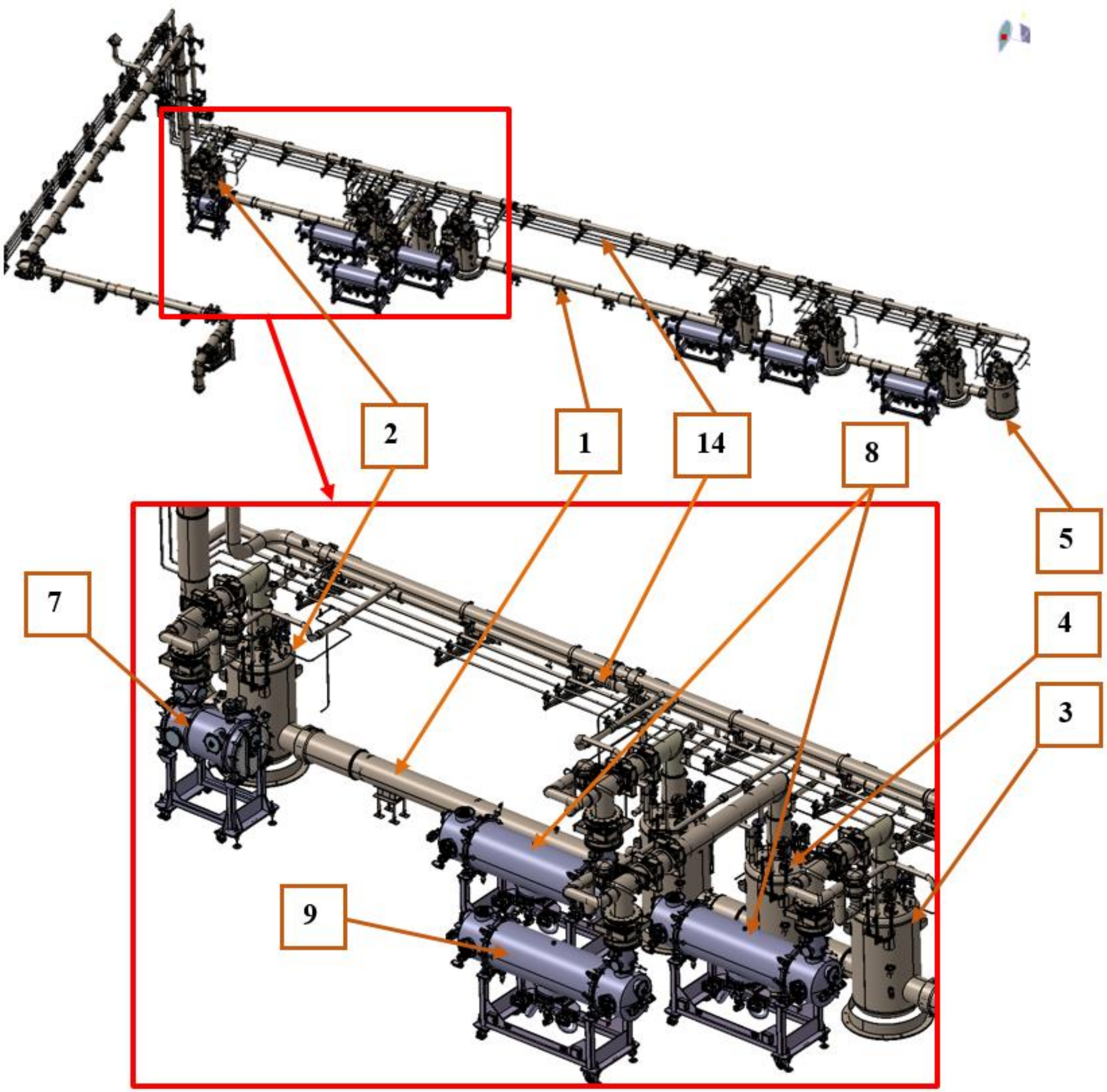
Maximal dynamic heat loads to four HZDR-like cryomodules has been estimated for 238 W at CW (continuous wave) operation mode, and for 240 W at LP (long pulses) operation mode (peak value 421 W, filling factor 57%).

Overall heat fluxes are of about 310 W @ 2 K. Taking into account the upgrade of the PolFEL to six HZDR-like cryomodules, a target cooling power is 460 W.

PolFEL cryogenic system

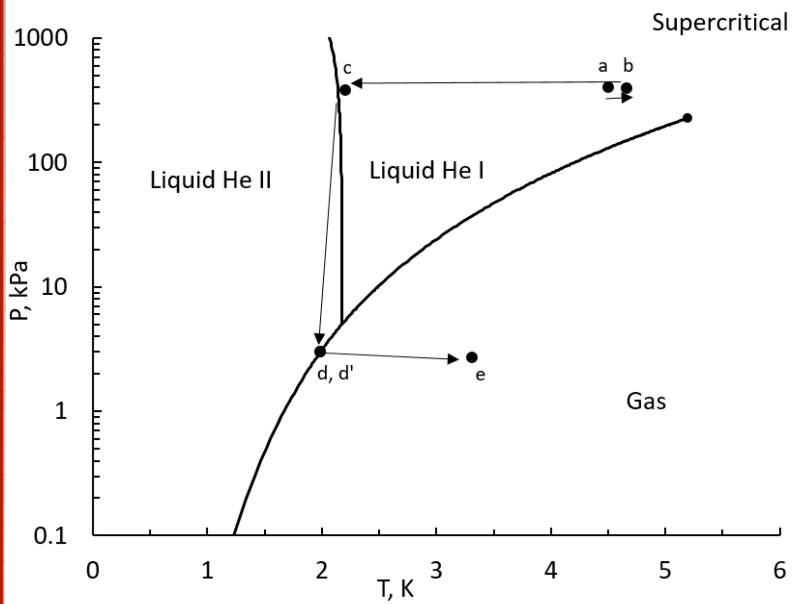


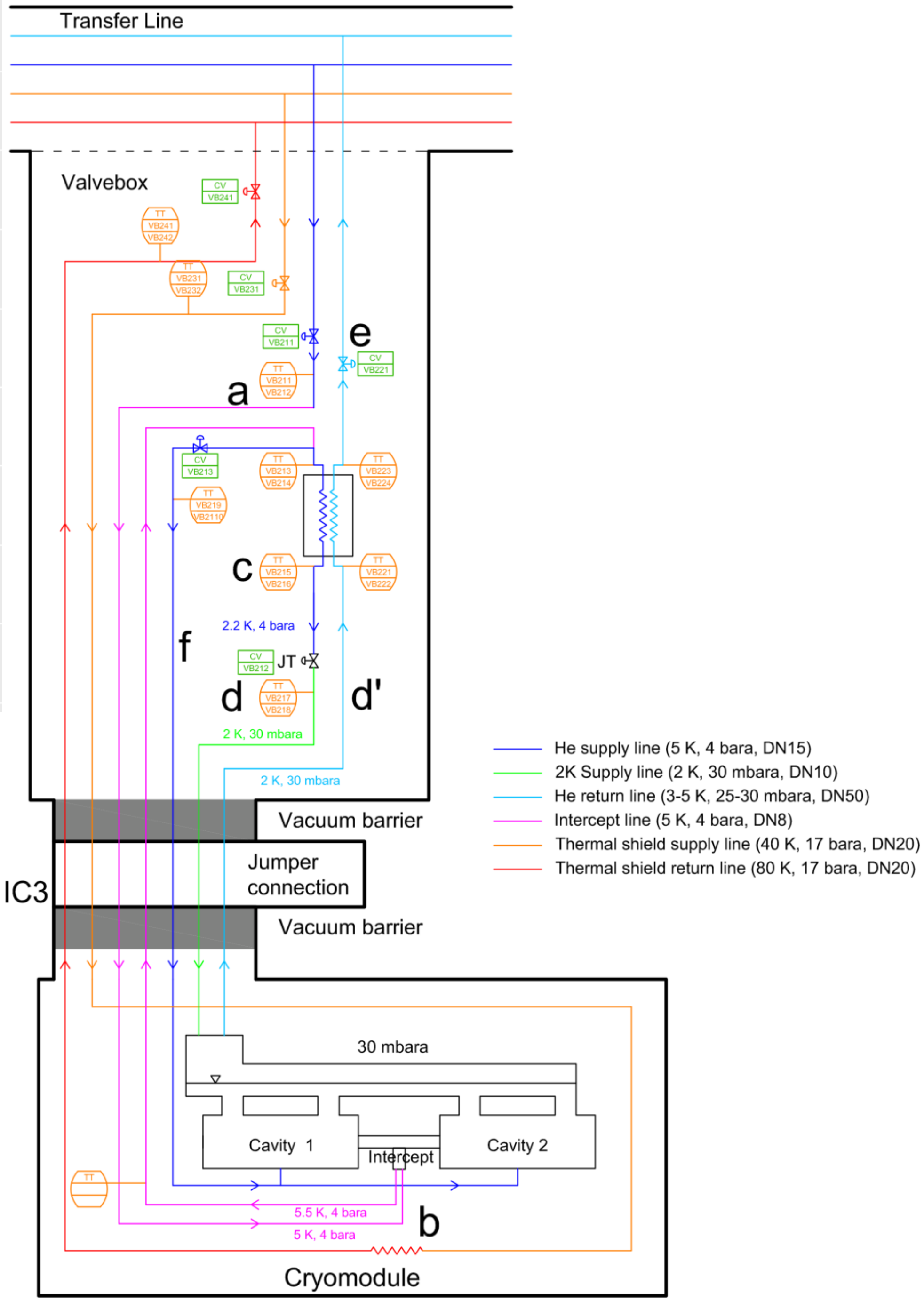
PolFEL cryogenic system



Valveboxes

The main task of the valveboxes is to provide the supercritical helium @5K to the cyomodule power couplers and to convert supercritical helium into superfuid helium @2K for the needs of RF cavities of the cryomodules





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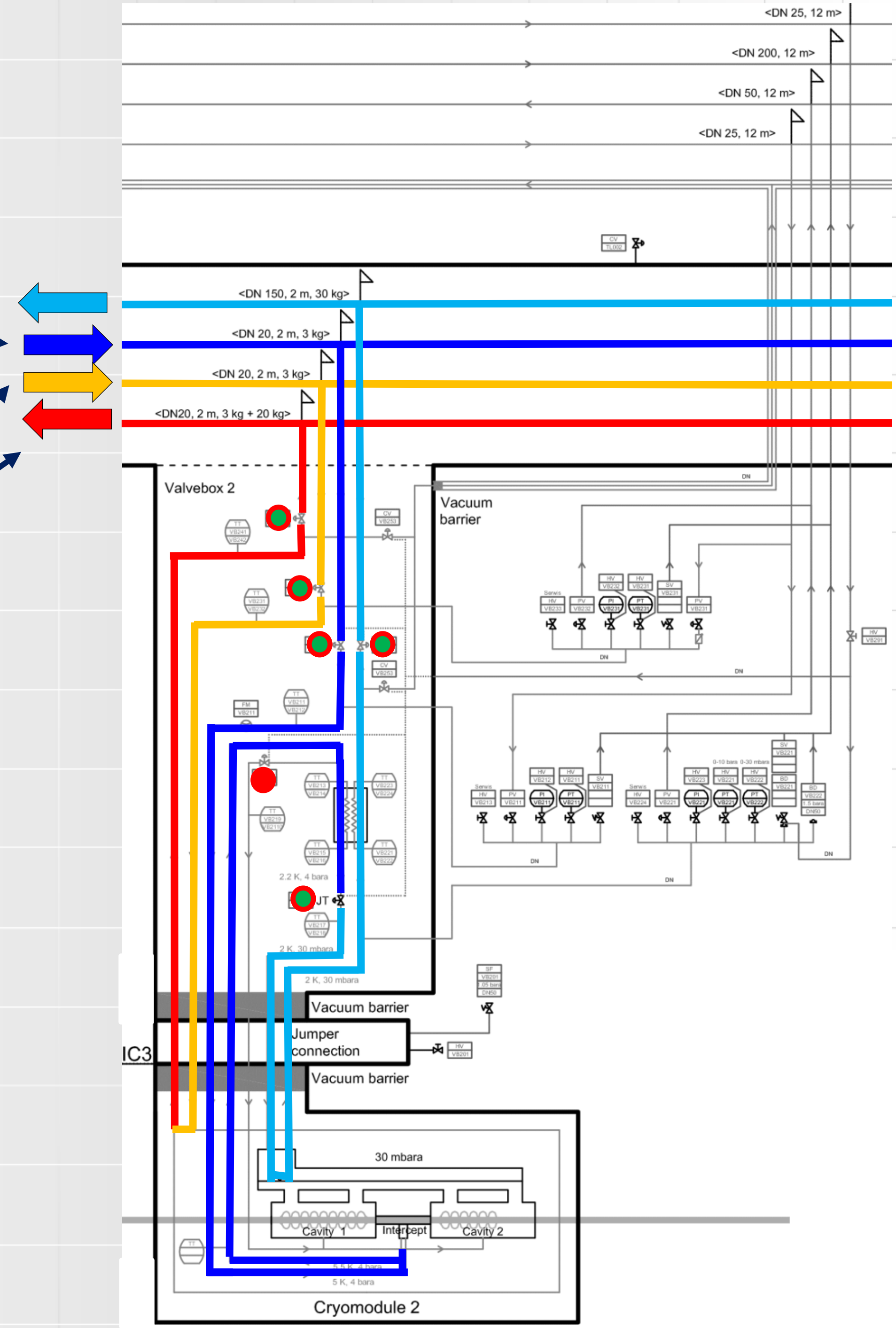
Flowscheme

He return line

He supply line

Thermal shield supply cooling cirquit

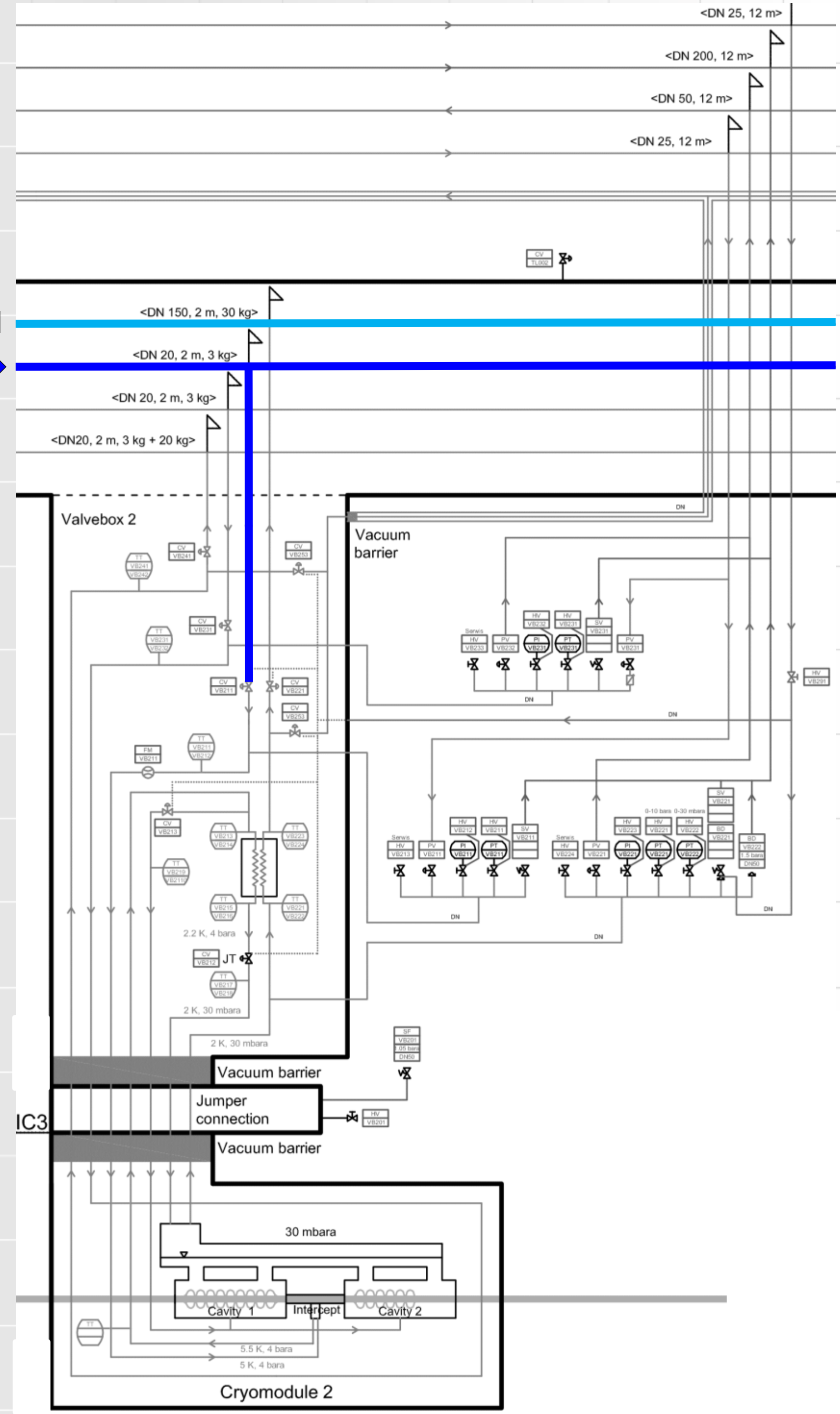


Nominal operational mode flowscheme

He return line

He supply line

Supercritical helium flows inside the transfer and is redirected from the main transfer line line into the valvebox located in the vicinity of the cryomodule.

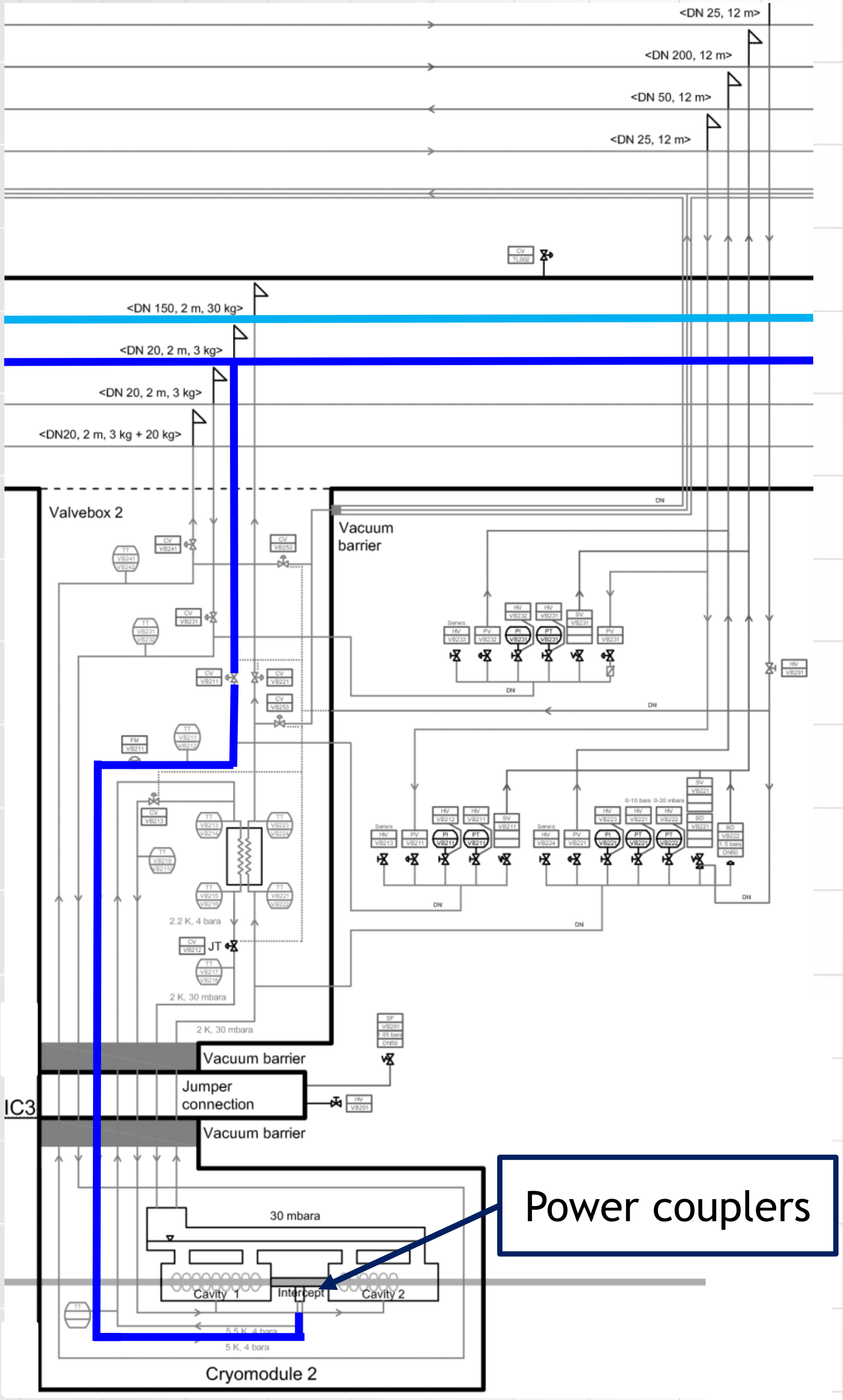


Nominal operational mode flowscheme

He return line

He supply line

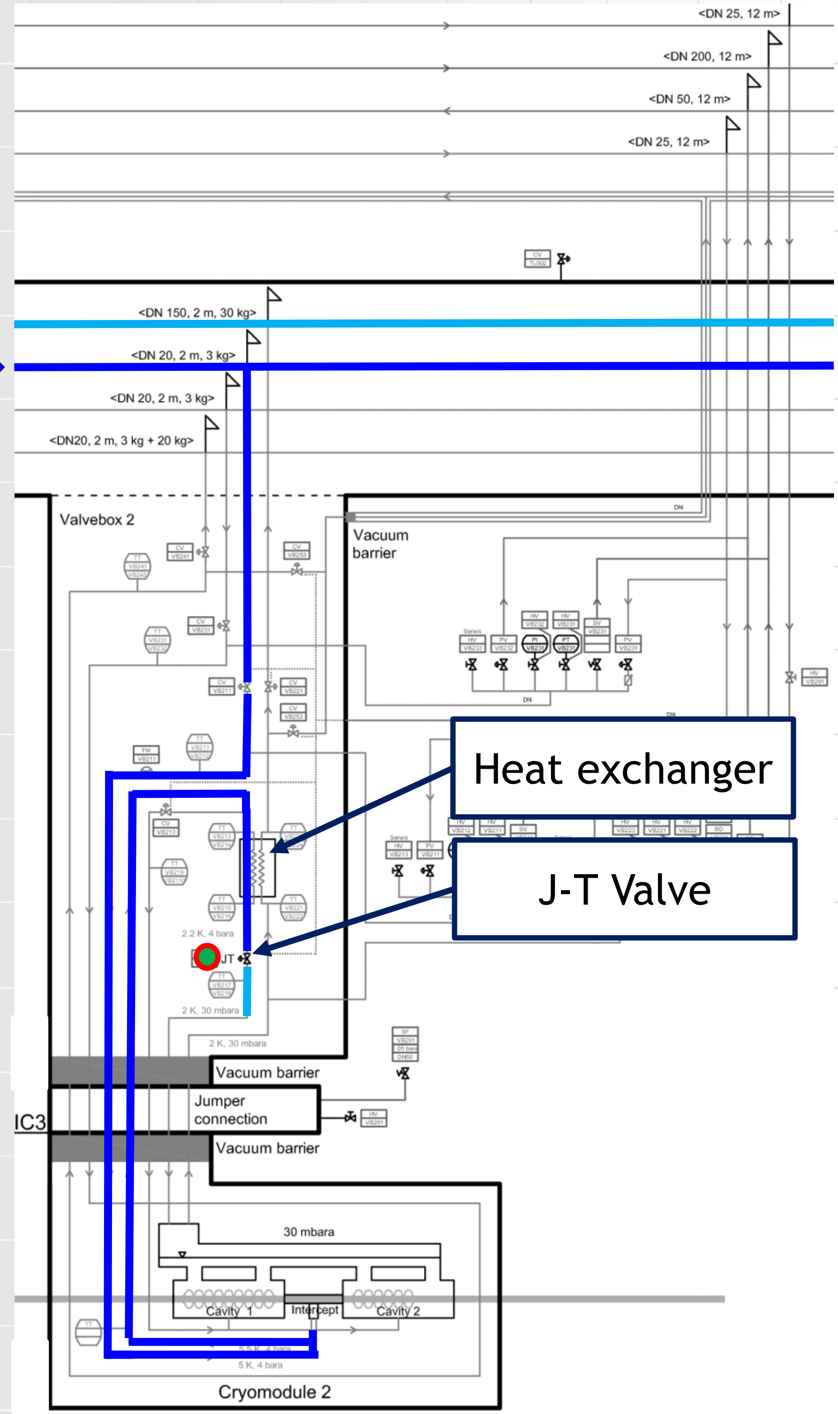
Supercritical helium is firstly delivered to the cryomodules in order to thermalize the power couplers at the temperature of 5 K



Nominal operational mode flowscheme

He return line

He supply line

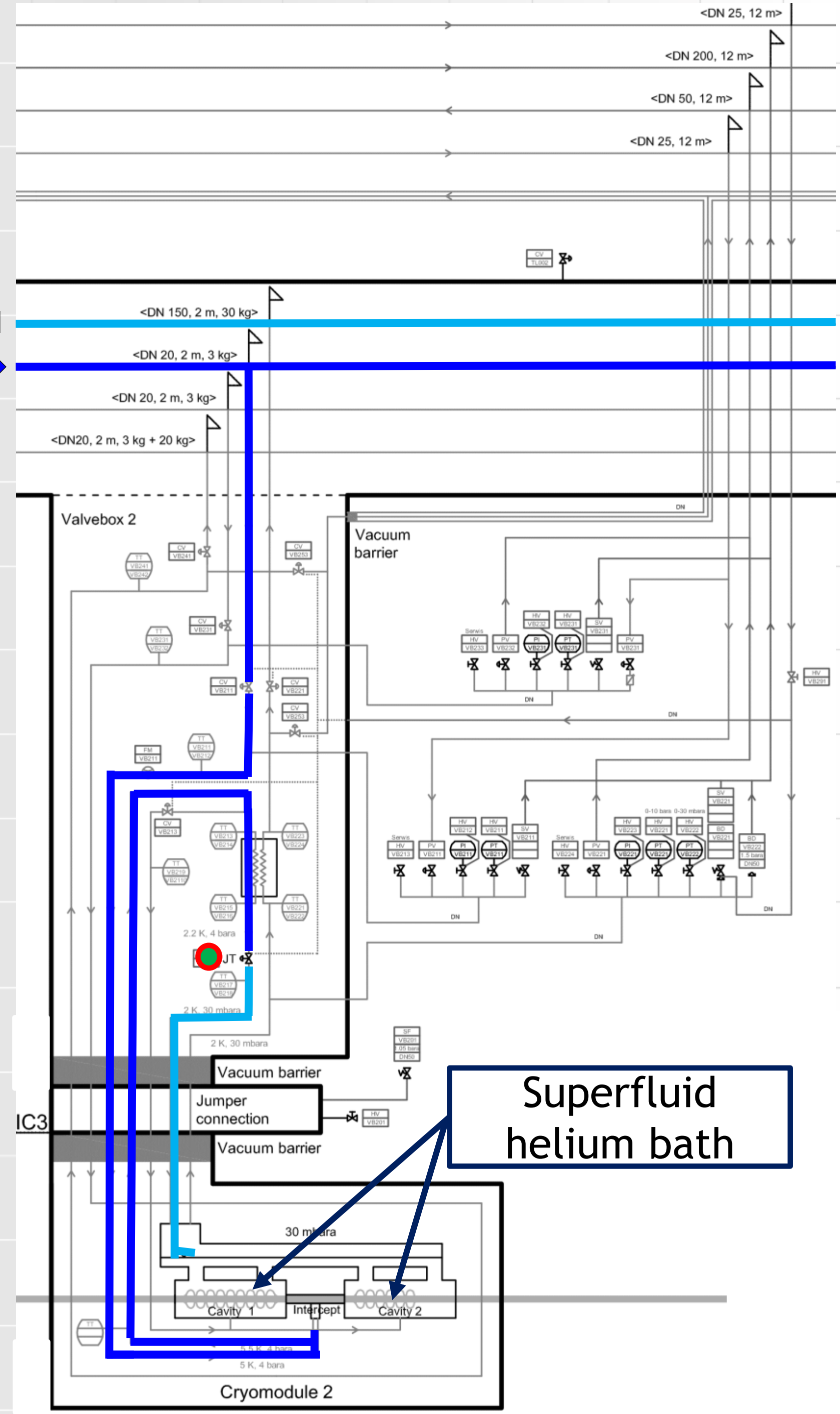


After the thermalization, supercritical helium flows back to the valveboxes in which it is pre-cooled to 2.2 K in a heat exchanger and subsequently throttled in the J-T valve into a the superfluid state required to cryostate the SRF cavities.

Nominal operational mode flowscheme

He return line

He supply line

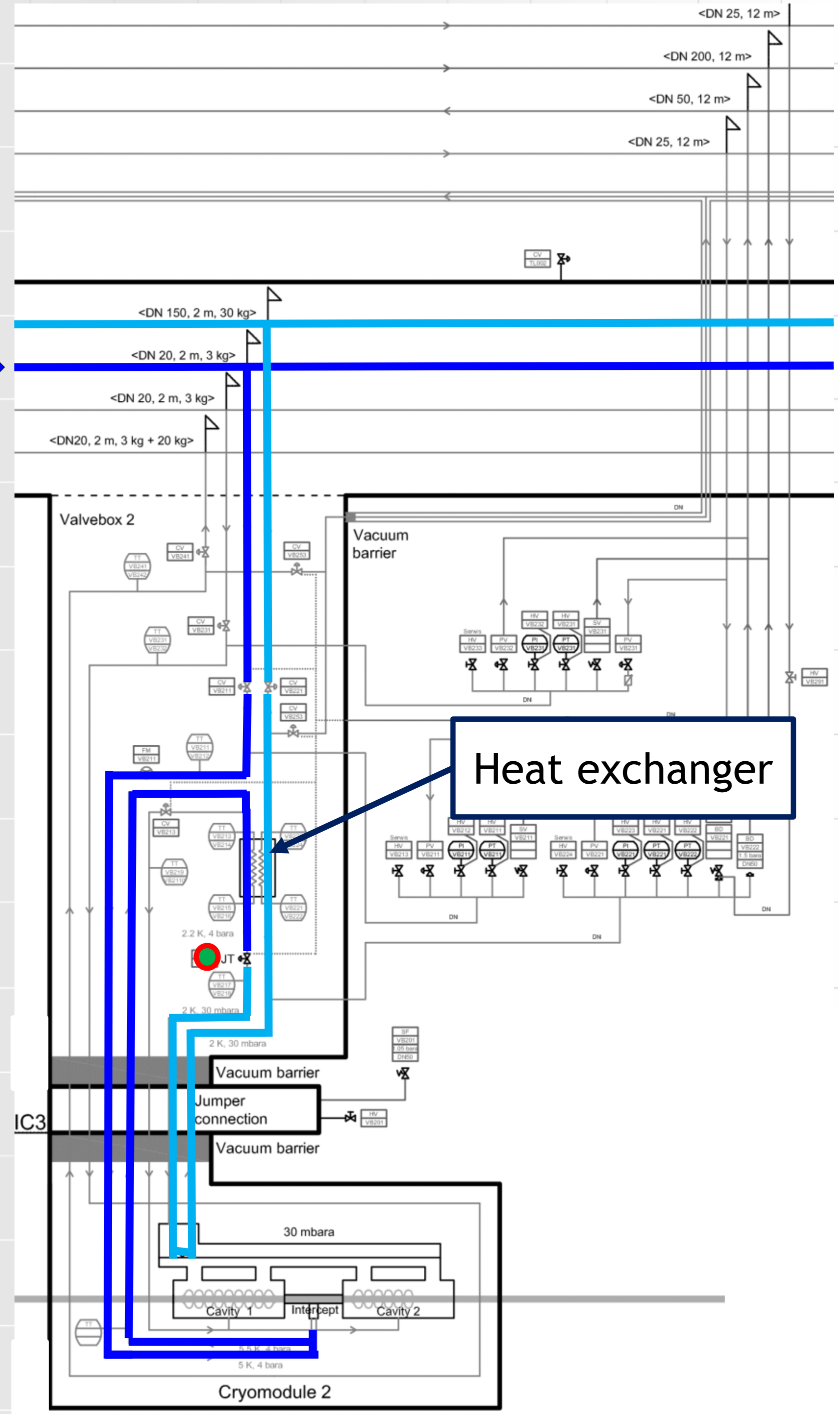


The superfluid helium thus obtained flows to the cryomodule, in which it vaporizes, receiving the heat generated in the cryomodule.

Nominal operational mode flowscheme

He return line

He supply line



After being vaporized, helium at a pressure of 30 mbara and a temperature of 2 K flows back to the valvebox. It subsequently passes through the low-pressure part of the heat exchanger and finally, through the transfer line, reaches the Helium Cooling System.

Design optimization of the Cryogenic system

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During the planning and design of both the transfer line and valve boxes, several optimization points were encountered. Considering and developing these points allowed for adjusting the CDS design to the specific needs of the cryomodules. Below are three exemplary optimization challenges:

1. Selection of the cooling medium for the cryomodule thermal shields (nitrogen/helium).
2. Cryostatization method for the cryomodule power couplers at 5 K.
3. Installation location for the cold compressors.

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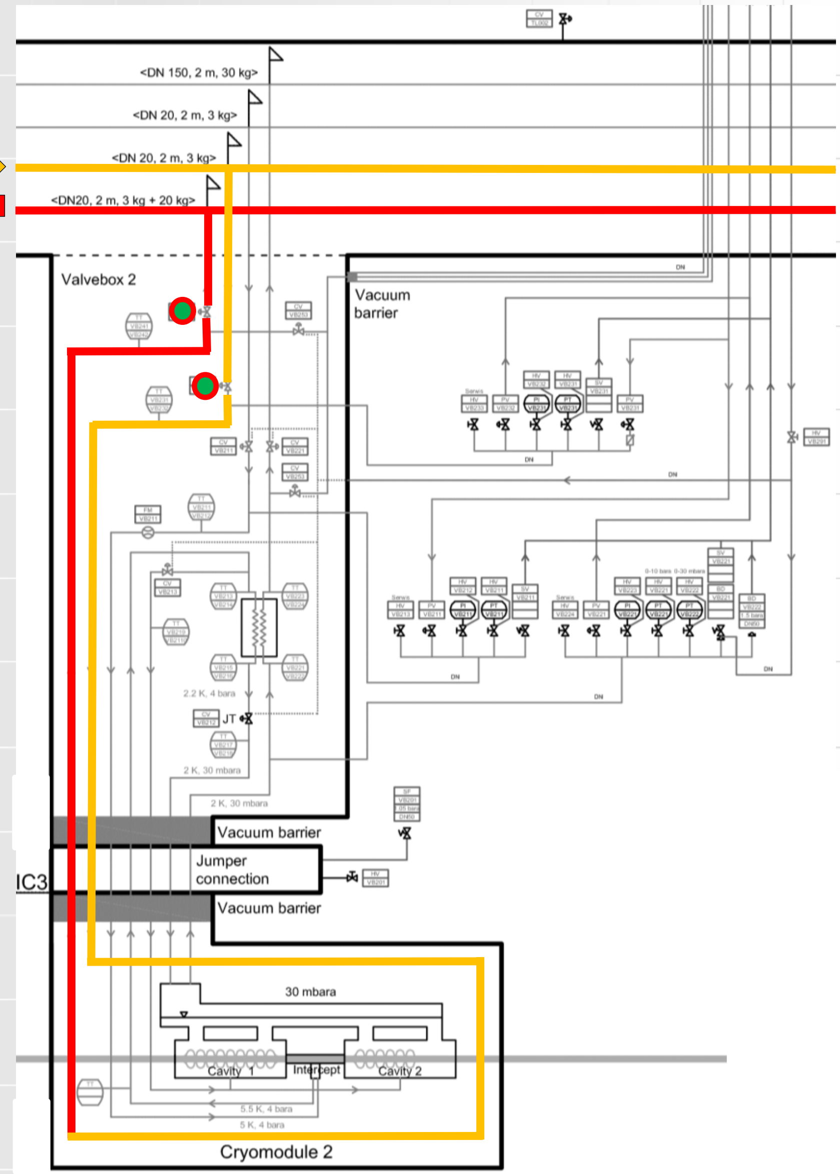
Design optimization of the Cryogenic system

Selection of the cooling medium for the cryomodule thermal shields (nitrogen/helium).

Thermal shield supply cooling cirquit



Designed heat influx to the thermal shield of CDS and the cryomodules is approx. 560 W

Using liquid nitrogen for cooling the thermal shield in a open cirquit would require a consumption rate of approximately 2.8 g/s (242 kg per day).

For economical and logistical reasons, it is more reasonable to use helium at temperatures of 40-80 K in a closed loop through the helium cooling system.

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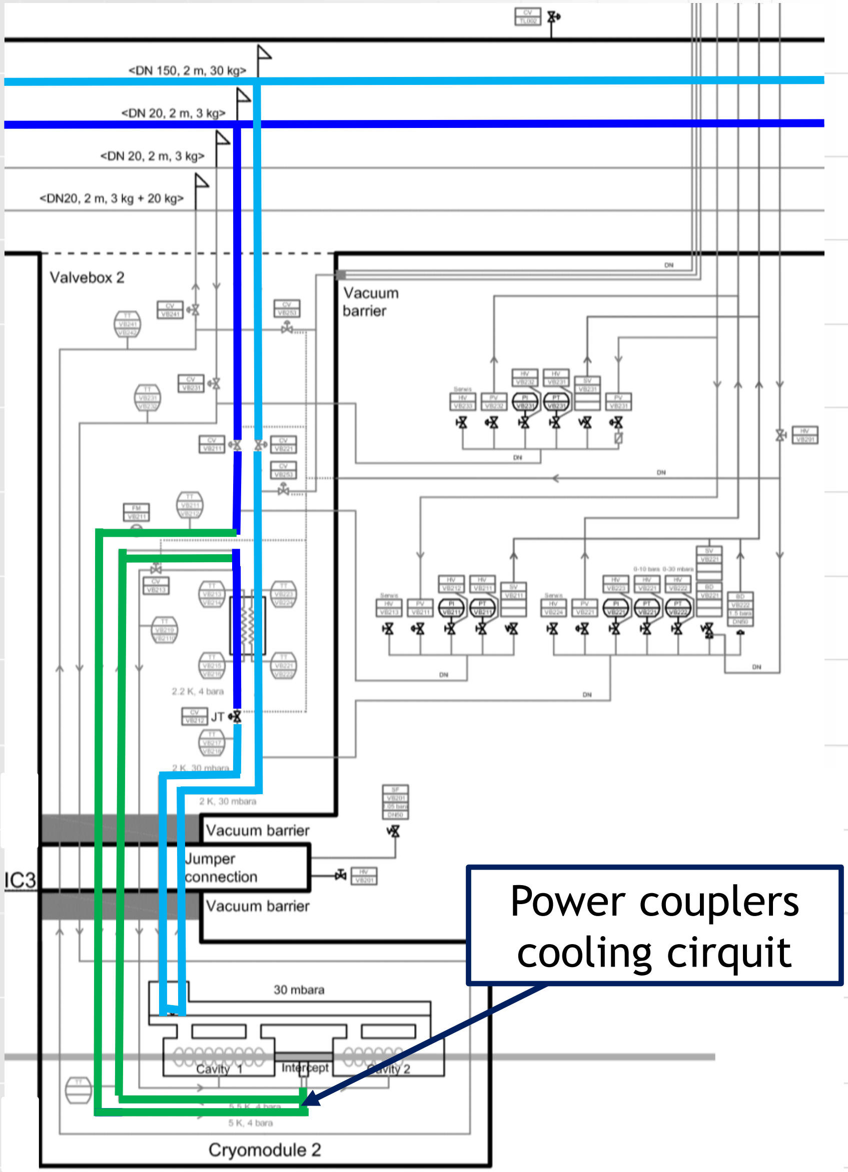
Design optimization of the Cryogenic system

Cryostating method for the cryomodule power couplers at 5K.

He return line

He supply line



Power couplers heat load: 3.3 W @ 5K

Helium can be provided by:

1. Dedicated helium cirquit form helium cooling system - static heat load: 27 W
2. Re-routing of the helium supply line (green line on the figure) – static heat load: 3 W

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Design optimization of the Cryogenic system

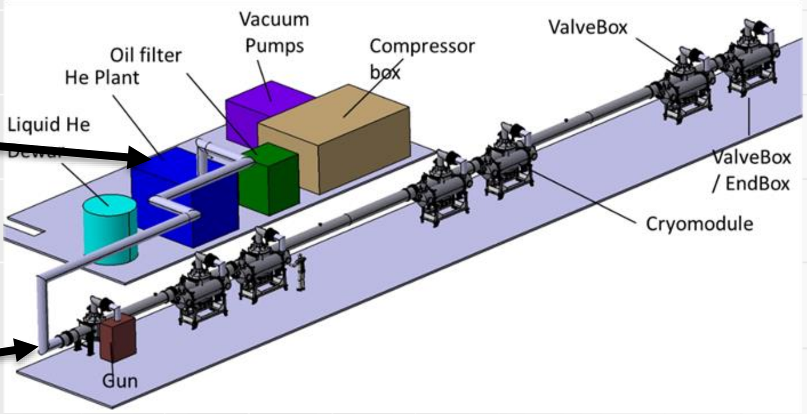
Installation location for the cold compressors.

At the initial stage of the project, two locations were considered:

1. The accelerator tunnel - near the operating cryomodule
2. The helium cooling system building

Location 2
ΔS. = 300 J/gs

Location 1
ΔS. = 258 J/gs



$$\sum \Delta S = \frac{q' \Delta T}{T^2 (1 + \Delta T / T)} + \frac{M}{\rho T}\left(-\frac{dp}{dx}\right) \cong$$

$$\frac{q' \cdot \Delta T}{T^2} + \frac{M_{HP}}{\rho_{HP} T}\left(-\frac{dp_{HP}}{dx}\right) + \frac{M_{LP}}{\rho_{LP} T}\left(-\frac{dp_{LP}}{dx}\right) \geq 0$$

$$W_{lost} = T_o \sum \Delta S$$

Control of the cryogenic system

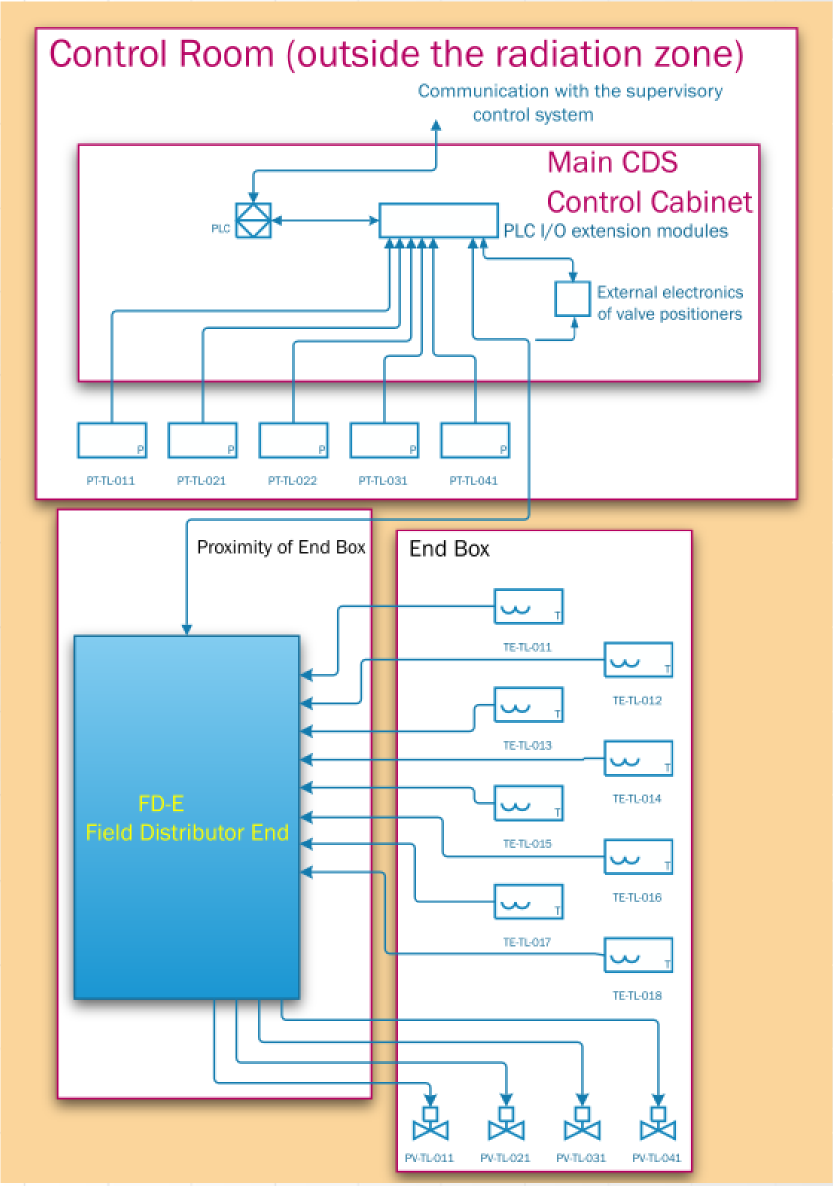


Fig. Example of CDS control subsystem

- Need for robustness of the automation devices to ionizing radiation of doses up to 0.5 MGy.
- The problem is approached by removing all electronic devices from the radiation zone and locate them in a safe zone behind a thick wall.

Conclusions

- Polfel will be the fiirst superconducting 2 K accelerator to be built in Poland.
- PolFEL cryogenic system will make use of helium in diversified thermodynamis states.
- The CDS system design has been optimised with use of the entropy generation analysis.

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Thank you for the attention